TECHNICAL REPORT NO. LWL-CR-02B71

LWL BENCH MODEL MOISTURE EXTRACTION DEVICE

Final Report
Contract No. DAAD05-70-C-0223

By

Michael G. Kelly
William H. Collins

Franklin Institute Research Laboratories
Philadelphia, Pennsylvania

March 1971

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U. S. ARMY LAND WARFARE LABORATORY

Aberdeen Proving Ground, Maryland 21005

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ABSTRACT

A feasibility evaluation of a bench model of a moisture extraction device developed by personnel from the U.S. Army Land Warfare Laboratory was conducted by The Franklin Institute Research Laboratories. The LWL bench model had an estimated efficiency of 15% using activated alumina and produced 2.9×10^{-2} gal/day/lb of dry alumina. By redesign, the efficiency could be increased to approximately 30×10^{-2} gal/day/lb of absorbent.

The study indicated that a 100 gal/day unit is feasible and would require approximately 300 lbs of absorbent. The overall size of the 100 gal/day unit is expected to be in the range of 100 to 200 cubic feet in volume, weigh 1,000 to 1,500 lbs. and, depending on absolute humidity, require a power input of 8 to 22 KW.

FOREWORD

Tests were run on a bench model moisture extraction device supplied by LWL. The device uses activated alumina as a collection medium and is capable of producing 2.9×10^{-2} gal/day/lb of dry alumina in environmental conditions of 74°F and 52%RH. Aside from two blowers the only moving part is a motor driven belt on which the activated alumina is adhered. The LWL unit weighs 45 lbs and measures 24" x 21" x 58" high. Based on the experimental results of this program, it is estimated that the output of this type of device could be increased to 33×10^{-2} gal/day/lb of dry alumina by careful redesign.

A similar device (scaled generally from that above) capable of producing 100 gal/day in moderate environmental conditions (75°F, 39%RH) would operate at 90% efficiency, require approximately 300 lbs of absorbent and a power input of 8 to 22 KW. The overall size of such a unit is expected to be in the range of 100 to 200 ft^3 and weigh 1,000 to 1,500 lbs. These parameters must be increased in inverse proportion to the absolute humidity.

Under limiting circumstances where the controlling factors are principally fundamental considerations such as heat to desorb, volume of air handled etc., a 100 gal/day output unit would have the following characteristics exclusive of the main power source.

Minimum Size - 50 ft^3
Minimum Weight - 800 lbs.
Minimum Power Requirements - 12.6 to 13.4 KW depending on RH.

Thus it would appear that further evolution of the concept is warranted, and it is recommended that the next phases include critical component improvement and more detailed adsorbent selection experiments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. LWL BENCH MODEL MOISTURE EXTRACTION DEVICE

1.1 Description of Operation

The LWL device is basically a water recovery device which may be used for obtaining water from a variety of media, although it is specifically designed to recover moisture from the air. The unique capability of this concept (in comparison to other water recovery methods such as distillation, freezing, reverse osmosis, etc.) is that it depends on the highly specific* process of chemisorption (adsorption) of water vapor in one "compartment" followed by its desorption in another compartment and transport as vapor to a condenser. Thus three purification stages can occur. The first would be vaporization from a "wet" material (in the case of "water-from-air" this occurs outside the apparatus); the second, specific adsorption on the drying agent; and the third "distillation" (desorption + vapor transport) to and condensation on a condenser. It could thus conceivably be used for selectively recovering potable water from salt water, exhaust vapor, urine, sweat, polluted water, etc. (See Table 1).

The bench model moisture extraction device supplied by LWL consists essentially of a continuous silicone rubber belt covered with activated alumina, a heating platen which conducts heat to the alumina to drive off the absorbed moisture and an air-cooled condensing plate to collect the vaporized moisture. Figure 1 is an overall view of the device. The belt is .010" thick silicone impregnated fiberglas and is 98" long by 3" wide. Granules of activated alumina are attached to the outer surface of the belt with a silicone rubber compound (RTV-102). Two small synchronous motors drive the belt past the heating platen and condenser plate at the rate of 2.35"/minute.

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*Especially with molecular sieves which can be made to exclude all molecules bigger than water (M. WT. 18).

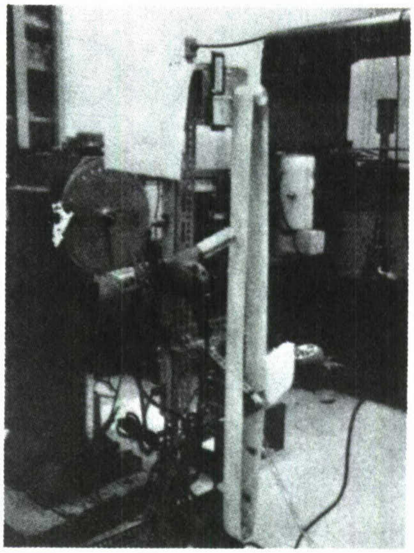

Figure 1. LWL Bench Model Moisture Collection Device

TABLE 1
Unusual Water Sources (for LWL Device)

Air (for ref.)	0.1 to 1 gal/6500ft^3 air Depending on relative humidity
Fresh Leaves	0.1 gal/10 lbs of leaves
Human Waste - Urine	0.5 gal/man/day
- Feces	0.01 gal/man day
- Sweat	0.05 gal/man day (varies widely)
Hydrocarbon (Gasoline) Combustion Products	1.25 gal/gal of hydrocarbon burned

TABLE 2
Output Capability of LWL Moisture Collection Device (Alumina Belt)

Test No.	Room Temp. (°F)	Rel. Hum. (%)	Absolute Humidity (lb H_2O/lb Air)	Time Period (hr)	Water Collected (cc)	Yield (cc/hr)	Yield (gal/day)
1	74	50	9.0×10^{-3}	5.0	10.0	2.0	1.3×10^{-2}
2	74	52	9.3	6.5	15.0	2.3	1.5
3	76	52	10.0	5.0	11.0	2.2	1.4
4	76	49	9.4	3.7	7.0	1.9	1.2
5	76	48	9.2	2.5	5.8	2.3	1.5
6	85	20	5.0	4.0	0.0	0.0	0
7	87	19	5.2	7.0	0.0	0.0	0
8	90	19	5.7	20.0	0.0	0.0	0
14	72	30	5.0	5.5	7.4	1.3	.8

As diagramed in Figure 2, the belt passes over the platen which is heated to about 375°F raising the temperature of the adsorbent material to about 225°F. The moisture condenses on the adjacent cooling plate which is kept at room temperature by the action of a blower directed at its back surface. A piece of cotton gauze attached to the condensing plate surface causes the condensed moisture to run into a collection vessel. In addition to the blower which cools the condensing plate a second blower directs ambient air at the activated portion of the belt (that portion which has passed through the heater-condenser).

1.2 Performance

The LWL prototype extraction device was operated in various temperature and humidity conditions as indicated in Table 2. The yield is seen to vary with temperature and humidity conditions; and, in general, it is not more than 2.3cc/hr for average ambient conditions. At low relative humidity and high temperature there was no yield of water from the bench model. Presumably, this was due to the inability of the bench

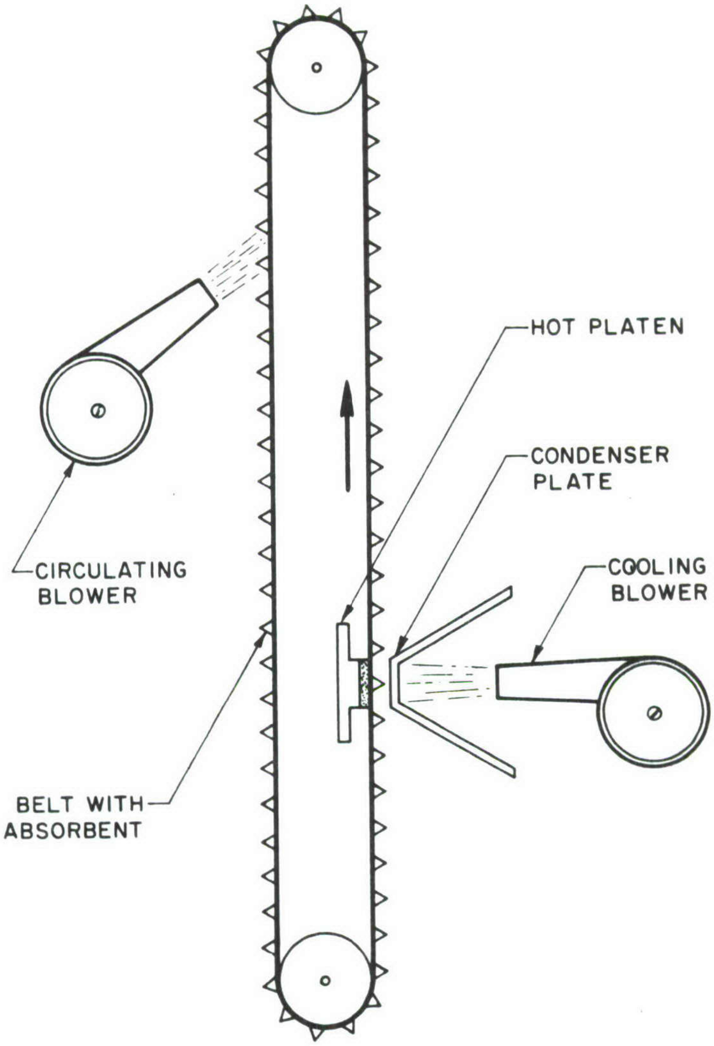

Figure 2. Arrangement of LWL Moisture Collection Device

model apparatus to work efficiently at the higher room temperatures. As discussed later in this report the use of a different drying agent can yield water even in low humidity environments.

Approximately 0.52 lbs of dry alumina are attached to the belt of the LWL device. Combining this value with the highest recorded yield per day (1.5×10^{-2} gal/day), the actual daily yield per lb of dry alumina is 2.9×10^{-2} gal/day/lb.

It is conceded that the bench model device was made to demonstrate the principle and therefore is not necessarily highly efficient and that there are many areas where improvement could be made. Therefore, the relatively low yield of 2.9×10^{-2} gal/day/lb of alumina is capable of being increased. In order to gain some insight into the yields which could be expected using a more efficient version of the LWL moisture extraction device a number of absorbing agents including activated alumina were subjected to dynamic absorption tests.

1.3 Absorption Potential of Drying Agents

The absorption capability or potential of activated alumina and other drying agents was determined experimentally by exposing dried (activated) samples to controlled environments and measuring percentage weight increase as a function of time. The samples of 2 to 5 grams of the agents being tested were dried in an oven at 200°C for a period of 2 hours. The dried samples were exposed to ambient conditions and weighed at intervals ranging from minutes to hours.

In addition to activated alumina, a small literature search revealed that a class of drying agents known as "molecular sieves" might be better in the proposed application. Accordingly, samples of representative molecular sieve drying agents were also tested in the above manner. The results of these tests which show the dynamic absorption potential of the selected drying agents are plotted in Figure 3 for high absolute humidity and in Figure 4 for low absolute humidity. Specific points from the curves of Figures 3 and 4 are listed in Table 3 along with some data from other water absorbing materials.

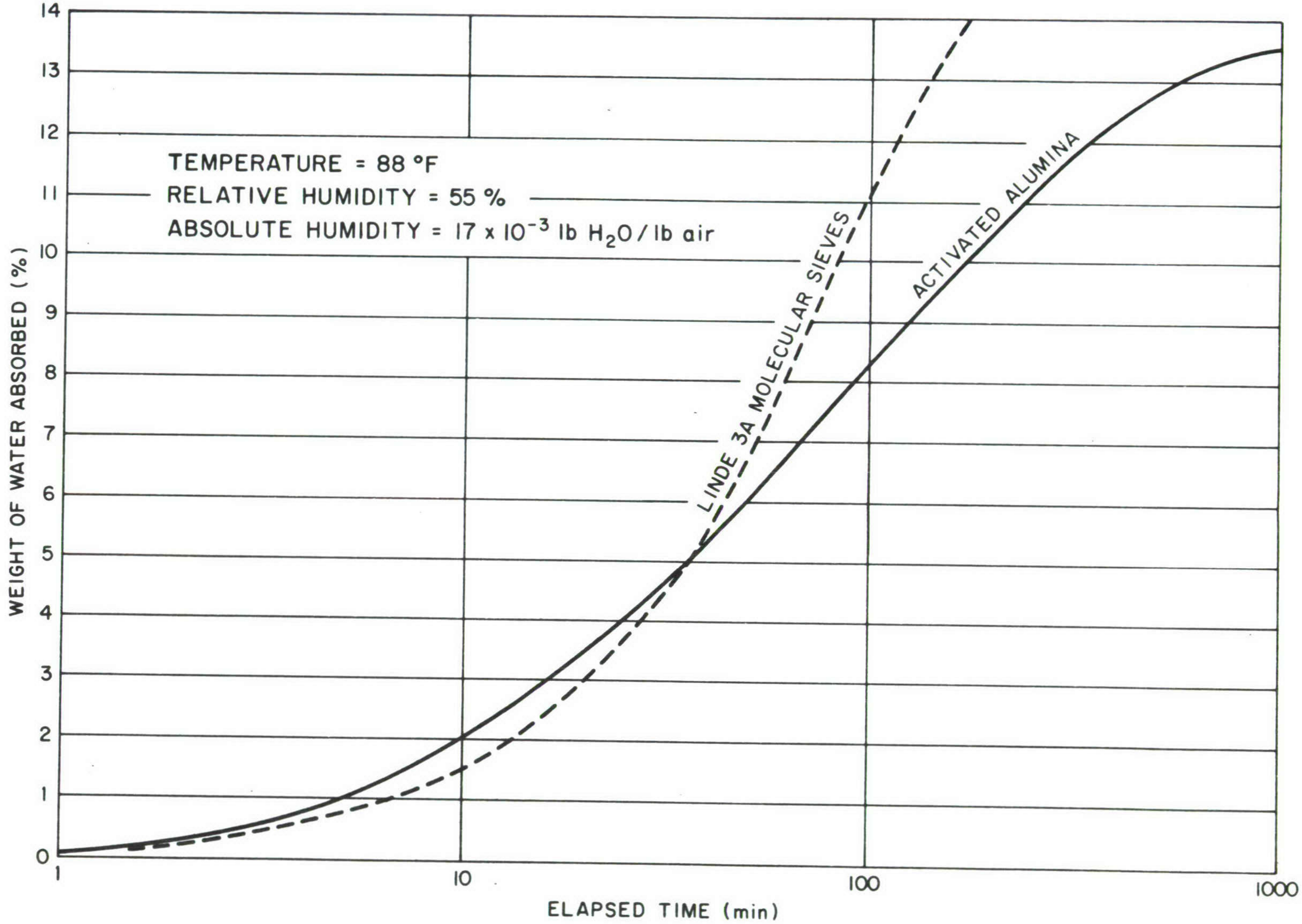

Figure 3. Dynamic Absorption (High Absolute Humidity)

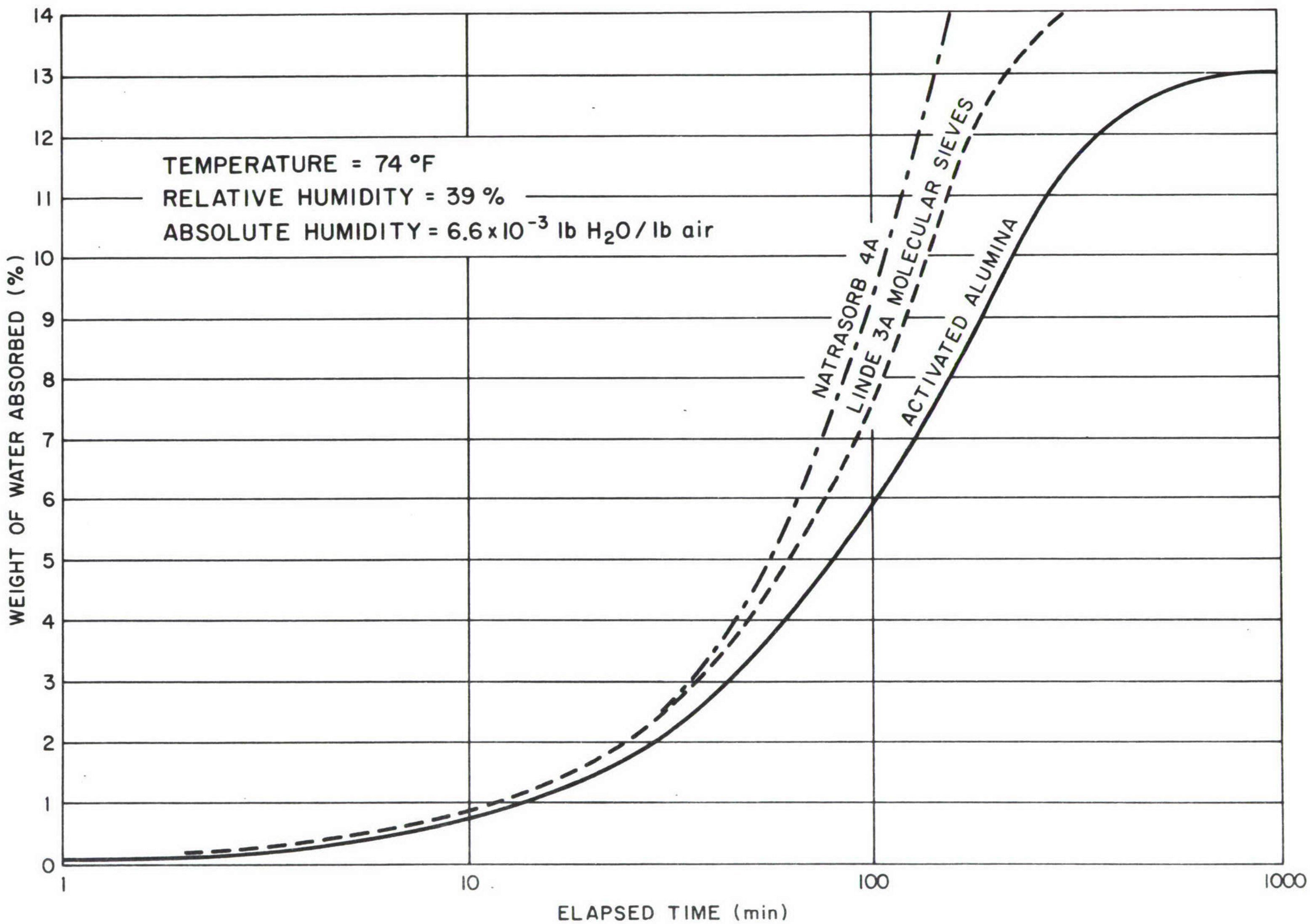

Figure 4. Dynamic Absorption (Low Absolute Humidity)

TABLE 3
Properties of Drying Agents

Agents	Dynamic Absorption Potential (42 min) Low (20%) Humidity	Dynamic Absorption Potential (42 min) High (80%) Humidity	Maximum Absorption Potential (1000 min) Low (20%) Humidity	Maximum Absorption Potential (1000 min) High (80%) Humidity	Comments
A. Inorganics					
Activated Alumina	2.8%	5.3%	13%	14%	
Molecular Sieves (Linde 3A)	3.3%	5.5%	17%	18%	Very specific for molecules the size & shape of water
Drierite ($CaSO_4$)	2.7%		14%		
$MgClO_3 \rightarrow MgClO_3 \cdot 6H_2O$			48%		Possible explosive hazard
$CaCl_2 \rightarrow CaCl_2 \cdot 6H_2O$				98%	
$CaO_2 \rightarrow CaO_2 \cdot 8H_2O$				200%	Possible explosive hazard
$NaSO_4 \rightarrow NaSO_4 \cdot 10H_2O$				127%	
P_2O_5			50%		Not reversible
B. Organics					
Cellulose Acetate				5-9%	Direct Immersion in H_2O
Cellophane				45-115%	Direct Immersion in H_2O
"Natrasorb" (Proprietary)	3.4%		20%	22%	(Sample received too late for detailed evaluation)
Sodium Carboxymethyl Cellulose			8%		
Hydroxy Ethylcellulose				6%	
C. Edibles					
Hydroxypropyl Cellulose ("Klucel")			2%	9%	
Gelatine					
Collagen					

Two facts are apparent from the data of Figures 3 and 4:

(1) in a 42 minute time period which is the time required for a complete revolution of the LWL bench model belt the molecular sieve agents are superior to the activated alumina.

(2) under near ideal drying and collection conditions the LWL device could yield between 6×10^{-2} and 11×10^{-2} gal/day of water; assuming the belt rotation time of 42 minutes was unchanged.

These data indicate, therefore, that the present LWL device is yielding about 15% of its maximum potential water output. As mentioned previously, there are features of the bench model which could be improved and it is likely that the device could be made to produce close to 100% of its potential. If this is true then the daily yield per lb of dry alumina which is given by

$$\frac{\text{Actual Daily Yield}}{\text{Wt. of Absorbent}} = \text{Specific Daily Yield},$$

would be as high as,

$$\frac{11.2 \times 10^{-2} \text{ gal/day}}{.52 \text{ lb of alumina}} = 21.5 \times 10^{-2} \text{ gal/day/lb},$$

for high humidity (T = 88°F, RH = 55%) conditions

and $$\frac{6 \times 10^{-2} \text{ gal/day}}{.52 \text{ lb of alumina}} = 12 \times 10^{-2} \text{ gal/day/lb}$$

for lower humidity (T = 74°F, RH = 39%) condition. Thus, to produce 100 gal/day of water, between 500 and 800 lbs of activated alumina would be required in the bench model configuration.

1.4 Power Requirement

The bench-model device as supplied has unnecessary power requirements. Two heavy duty blowers are used for condenser cooling and air circulation while the platen of an electric iron is used for the heating platen. Much power is wasted thus an estimate of the actual power requirements is necessary. Table 4 is a list of the estimated necessary power requirements for each component of the LWL device based on available hardware specifications.

TABLE 4
Estimated LWL Bench Model Power Requirements

Heating Platen (6 in^2 @ 375°F)		125 watts
Cooling Fan (125 cfm)		20 watts
Circulating Fan (125 cfm)		20 watts
Belt Drive Motor (synchronous)		3 watts
	Total	168 watts

Even this power requirements could be reduced considerably by redesign of the device. It should also be noted that the power requirements for larger scale units would not necessarily increase in direct proportion to the size of the extraction device. Proper insulation and air ducting would keep the requirements of a large unit down.

2. AREAS OF IMPROVEMENT

2.1 Absorbent Material

The dynamic absorption tests indicated that molecular sieves would be a better absorbent material than activated alumina especially at lower humidities. In order to test this a silicone belt with Linde 3A molecular sieves was fabricated to fit the LWL device. The device was then run at various temperature and relative humidity conditions with the results shown in Table 5. It can be seen upon comparison with the data of Table 1 for the alumina belt that the molecular sieve belt yields more water per unit time than the alumina belt. In fact where the alumina belt yielded no water at low humidity, high temperature conditions the molecular sieve belt continues to yield water.

The grain size of the absorbent material will have an effect upon its absorbent capability. Without more extensive testing, however, it is difficult to determine the quantitative effects. In general smaller grain sizes should yield higher absorption rates.

TABLE 5
Output Capability of LWL Moisture Collection Device (Molecular Sieve Belt)

Test No.	Room Temp. (°F)	Rel. Hum. (%)	Absolute Humidity (lb H_2)/lb Air $\times 10^{-3}$	Time Period (hr)	Water Collected (cc)	Yield (cc/hr)	Yield (gal/day)
9	76	30	5.7	1.7	4.0	2.4	1.5×10^{-2}
10	74	29	5.2	4.9	13.6	2.8	1.8×10^{-2}
11	87	17	4.6	25.0	5.0	0.2	0.13
12	94	18	4.7	1.5	0.3	0.2	0.13
13	72	22	3.6	4.0	4.0	1.0	0.63

2.2 Absorbent Transport

Presently, the absorbent material is cemented to a non-porous, silicone rubber belt with a silastic compound. This condition certainly prevents total exposure of the absorbent to the ambient air. A better method might be to sandwich the abosrbent between layers of mesh so that air (both heated and ambient) could be passed directly through the absorbent.

2.3 Heater Platen

A single or multiple strip heater could serve well as a hot platen to cause desorption of the absorbent. The heater element should be properly insulated to avoid losses since it consumes the most power. If a mesh holding and transport technique is used with the absorbent, then a hot air blower could be used instead of a stationery platen. Of course, it may be feasible to use radiant energy supplied by electrical or solar means to raise the temperature of the absorbent. Radiant solar energy, in fact, might be an efficient and inexpensive source of heat in a number of situations (e.g., desert or tropics).

2.4 Condensing Plate

The present condensing plate is inefficient since its surface area is relatively small. A finned condenser would present more surface area while still providing proper moisture runoff. Its cooling blower could serve also as an air circulating blower for forcing air across the activated absorbent. It should be noted that the design of the condenser is the area where the greatest amount of improvement is needed.

2.5 Circulating Blowers

By forcing moisture-laden air past or through the absorbent material some improvement of the absorption potential over and above that obtained in the previously discussed dynamic tests will be obtained. Furthermore, in a large capacity unit capable of producing 100 gal/day forced air circulation is a necessity. Table 6 shows the volume of dry air per 100 gallons of water at three different humidity conditions.

TABLE 6

Dry Air Volume Containing 100 Gal. of Water

Temp = 74°F

RM	Volume of air/100 gal H_2O
10%	6.5×10^6 cu. ft.
50%	1.2×10^6 cu. ft.
90%	$.63 \times 10^6$ cu. ft.

A circulating fan must be capable of moving a sufficient volume of moisture-laden air, as indicated by Table 6, past the absorbent in order for it to function effectively.

It is also important to cool the freshly activated absorbent (as it leaves the heating area) as quickly as possible so that the exposure time is optimized. Proper ducting of the blower circulated air is necessary in this regard.

2.6 Absorbent Exposure-Cycle Time

The length of time which the absorbent is exposed to moisture laden air is fixed at 42 minutes in the LWL device. However, the use of color indicator absorbent showed that most of the water was adsorbed within 20 inches of belt travel. Using the dynamic absorption data from Figure 3, Table 7 shows ideal daily yield for various belt cycle times. It is immediately apparent that a belt cycle time of 5 to 10 minutes would yield about 50% more water on the LWL device and, in fact, other devices of the same nature. Of course, the optimum cycle time may vary with the use of other drying agents (such as molecular sieves).

TABLE 7
Maximum Possible Yield of LWL Device as a Function of Belt* Cycle Time (High Humidity)

Belt Cycle Time (min)	Weight of Water Absorbed (%)	Yield (gal/day/lb of dry alumina)
3	0.5	27.8×10^{-2}
5	1.0	33.4
10	2.0	33.4
20	3.4	28.4
42	5.4	21.5
100	8.3	13.9
200	10.5	8.8

*Belt is 96" long, but these data apply to any belt length.

3. CONCLUSIONS AND RECOMMENDATIONS

Based on the foregoing analysis it seems likely that a large scale device capable of producing 100 gal/day would be feasible, especially in moderate R.H. conditions.

3.1 Scaled Up LWL Water Recovery Unit

1. The LWL bench model device has an estimated efficiency of 15% using activated alumina. Increasing this efficiency to a higher value (e.g., 90%) by redesign would yield as much as 30×10^{-2} gal/day/lb of alumina. ($.90 \times 33.4 \times 10^{-2}$, from Table 5).
2. Increasing the circulating velocity might raise the yield by 10% to 33×10^{-2} gal/day/lb of alumina ($30 \times 10^{-2} + .10 \times 30 \times 10^{-2}$.
3. With a yield of 33×10^{-2} gal/day/lb of alumina the quantity of alumina required to produce 100 gal/day would be $100/33 \times 10^{-2} = 300$ lbs.
4. Power requirements of 100 gal/day device can be estimated by scaling up the requirements of the present bench model. Table 8 presents the scaled up requirements with high and low ranges of the estimates. These range from 8 to 22 KW.

These estimates are for high absolute humidity conditions (74°F, 39% Rel. Hum., 17×10^{-3} lb H_2O/lb air). To obtain the same yield of 100 gal/day at lower absolute humidity conditions would require almost a direct, one-to-one scaling of these estimates. Thus a system for extracting 100 gal/day from air having extreme, desert-type moisture content (120°F, 5% Rel. Hum., 3.8×10^{-2} lb H_2O/lb air) would require a scaling up of power requirements and quantity of absorbent by a factor of

$$\frac{17 \times 10^{-2}}{3.8 \times 10^{-2}} = 4.5$$

TABLE 8
Estimated Prototype* 100 gal/day
Power Requirements

Component	Power Required (Watts) Low Est.	High Est.
Heater Element (600 to 1800 in^2 @ 375° F)	6,000	18,000
Cooling Fan (2 to 3 HP)	1,500	2,200
Circulating Fan (0 to 1 HP)	-	750
Belt Drive (1/3 to 3/4 HP)	250	560
Total	7,750	21,510

*Based on strip heaters and fan cooling.

Since the dynamic absorption capability of absorbents such as molecular sieves are slightly better than alumina at low absolute humidities (see Figure 4) the factor of 4.5 for extreme desert conditions might be reduced slightly.

The volume and weight of a 100 gal/day unit can only be roughly estimated. The density of 8-14 mesh, activated alumina is 58 lb/ft^3; therefore, 300 lbs of alumina would occupy 5.2 ft^3. The size of the entire unit is difficult to estimate since all details have not been studied. Considering a system where a heating platen and circulating blower were used an approximate size of 6' x 5' x 5' seems likely, with a total weight near 1,000 lbs.

3.2 A Theoretical 100 gal/day Unit

Under limiting circumstances where the controlling factors are principally fundamental considerations such as heat to desorb, volume of air to be handled, etc., a 100 gal/day output unit would have the following characteristics:

Minimum Size: 50 ft^3

Minimum Weight: 800 lbs

Minimum Power Requirement: 13.4 KW

Table 9 is a listing of the components which would be utilized in the 100 gal/day unit. Included in the table is the power requirements (if any) for the components along with component weight and volume. It should be noted that (a) the total weight figures do not include auxiliary hardware and supports, (c) the total volume calculated is for the actual components and does not include auxilliary components and intercomponent space, and (c) the power requirements are based on electrical heaters and could be significantly reduced if other heating systems (solar, waste heat, etc.) could be incorporated.

3.3 Recommendations

1. FIRL recommends that a program be initiated to develop a pilot sized unit to recover moisture from air before proceeding with a 100 gal/day unit. The capacity of the pilot sized unit should be in the range of about one to 20 gallons per day.
2. The proposed program should include critical component improvement and a more detailed adsorbent selection. In this program, improved efficiency of the components (heaters, condensors, blowers, etc.) would be a major consideration along with the selection of the optimum adsorbent material.

TABLE 9
Optimum Components for 100 Gallon/Day Unit

	Power Requirements (Kilowatts per hour at 100 gallons/day)		Volume Cu.Ft.		Weight Lbs.	
	Low Humid.	High Humid.	Low Humid.	High Humid.	Low Humid.	High Humid.
Blower	1.02	0.25	35.0	4.0	222	33
Drive Motor/Gears	.30	.30	2.0	2.0	75	75
Adsorbent	--	--	5.2	5.2	300	300
Heater	12.05	12.05	0.4	0.4	20	20
Belt and Bearings	--	--	1.3	1.3	125	125
Condenser	--	--	4.5	4.5	64	64
TOTALS	13.37 KW	12.60 KW	48.4 ft^3	17.4 ft^3	806 lbs	627 lbs

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13. ABSTRACT

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